Journal of Applied Sciences

ISSN 1812-5654

ANSInet
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http://ansinet.com

Journal of Applied Sciences 8 (1): 49-58, 2008
ISSN 1812-5654

Erosion Analysis of Şahin Creek Watershed (NW of Turkey) Using GIS Based on Rusle (3d) Method

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Abstract: The aim of this study is to determine the potential erosion risk and to predict long time average annual soil loss resulting from raindrop splash and runoff and controlling factors in Şahin Creek watershed which is located on the northern part of Edremit Gulf in the Northwest of Turkey. For this purpose in order to determine controlling factors and find out the rate of potential erosion risk, Geographical Information Systems (GIS) based Revised Universal Soil Loss Equation (RUSLE) model was used. All factors used in the RUSLE were calculated for the watershed using local data. RUSLE-factor maps were made. According to result of this study five erosion risk classes which are low, slight, moderate, high, severe were defined. The mean values of the R-factor, K-factor, LS-factor, C-factor and P-factor were 305 km^{-2} h^{-1} a^{-1} (MJ ha^{-1} $year^{-1}$), 0.54 Mg h MJ^{-1} mm^{-1} (ton ha^{-1} $year^{-1}$), 15.03, 0.05 and 0.95, respectively. The mean annual soil loss is estimated to be 43 tons per year per hectare. There is more erosion in the upland on the north and step slopes in the west of Şahin creek watershed.

Key words: Soil loss, erosion, RUSLE (3d), geographic information systems, remote sensing, şahin creek watershed

INTRODUCTION

Water erosion is a serious and continuous environmental problem in many parts of the world. The need to quantify the amount of erosion and sediment delivery in a spatially distributed form has become essential at the watershed scale and in the implementation of conservation efforts. Sediment yield from a watershed is an integrated result of all water erosion and transport processes occurring in the entire contributing area (Lane *et al*., 2000). The total sediment yield thus depends on both erosion at the various sediment sources such as crop, range and forest lands and the efficiency of the system to transport the eroded material out of the watershed (USDA-SCS, 1972). The potential for soil erosion varies from watershed to watershed depending on the configuration of the watershed (topography, shape), the soil characteristics, the local climatic conditions and the land use and management practices implemented on the watershed. RUSLE, with great acceptance and wide use, is simple and easy to parameterize and requires less data and time to run than most other models dealing with rill and interrill erosion (Jones *et al*., 1996). The combined use of Geographic Information System (GIS) and erosion models has been shown to be an effective approach to estimating the magnitude and distribution of erosion (Mitasova *et al*., 1996; Molnar and Julien, 1998; Millward and Mersey, 1999; Yitayew *et al*., 1999). Erosion and spatially distributed sediment delivery in a watershed has been modeled by Ferro and Porto (2000) based on USLE and the travel time concept. This approach was incorporated into a GIS by Jain and Kothyari (2000). GIS facilitates efficient manipulation and display of a large amount of geo-referenced data. More importantly, it allows easy definition of spatial subunits of relatively uniform properties. Hence, with the aid of GIS, erosion and sediment yield modeling can be performed on the individual subunits. The identification of the spatially distributed sediment sources makes possible the implementation of special conservation efforts on these source areas.

Many properties affect the type and size of erosion in an area. But at the first look, it is possible to say that the features belong to landforms like bed rock, elevation, gradient and aspect; climate elements such as temperature, precipitation, humidity and wind and combination of different integrities like flora and human; are controlling the erosion. The size of the erosion is generally determined by considering the carried soil quantity. The minerals and rocks constituting of the

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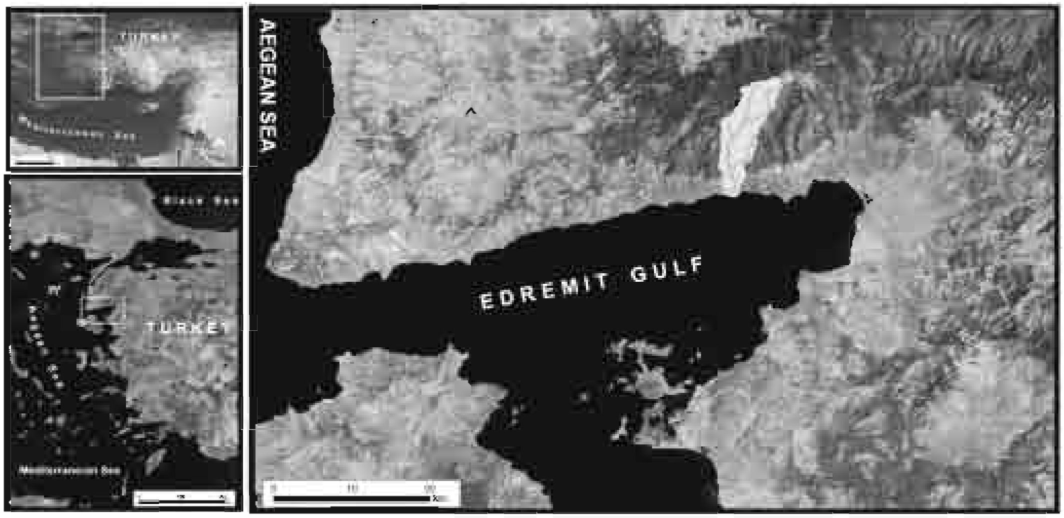

Fig. 1: Location of şahin creek catchment

earth's crust are always undergoing changes on physical and chemical ways with the effects of water and air. These events form loose cover deposits; being broken and decomposed on the bed rock. In the next process, organic elements are added to this inorganic cover deposits and the formation of soil eventuates. Especially executing of agricultural activities is possibly only in deep soils being rich in minerals. However, the outside factors and processes try to move this cover constituted with the decomposition of the bed rock to different places. Because of this, the process named as erosion should be perceived as an important trouble to be taken into consideration in its effects to human life (Morgan, 1995).

The aim of this study is to determine the potential erosion risk and to predict long time average annual soil loss resulting from raindrop splash and runoff and controlling factors in Şahin Creek watershed which is located on the northern part of Edremit Gulf in the northwest of Turkey.

Description of the study area: The study area is located 477000-486000 East and 4379000-4386000 North (European Datum 1950-UTM Zone 35N) coordinates on the north of the Gulf of Edremit, on the northwest of Turkey (Fig. 1). The study area is approximately 62.35 km^2 in size and consists of various topographical features (flat, rolling, hilly and mountainous).

The geology of study area can be broadly divided into metamorphic rocks in the north and sedimentary rocks in the South. Generally metamorphic rock groups constituting Kazdağ massive are forming the base of the study area. Metamorphic rocks like metagabro, marble and gneiss belong to pre-Jurassic period occur in the area. Upon these main rocks, contact metamorphic rocks like hornfels, granite and vollastonite types and Jurassic rocks like granodiorite, conglomerate, metagraywacke and siltstone occur. In the lower parts of the basin, there are fluvial deposits formed mostly in Quaternary period (Bingöl, 1969).

The area has a very diverse environment, with an altitudinal variation from 0 m at sea level in the estuary of Şahin creek to the uplands 1774 m above sea level on the peak of the Kaz (Ida Mt.) Mountain. This area has various microenvironments, partly reflecting it's geological, geomorphological, pedological and biogeorgpahical diversity (Efe, 2000; Efe and Tagil, 2007).

In Şahin creek catchment, the topography largely consists of a series of deep cut valleys and steep slopes. When traveling northwards up the mountain, the topography becomes very rugged as they become narrow gorges with few areas suitable for either cultivation or habitation. Before reaching Kaz mountain peak, the topography becomes varied and spectacular, with steep hills and cliffs. The slope gradient in Şahin Creek watershed increases in the uplands of the basin; however, they decrease in lower parts. In the most part of the study area, the gradient is higher than 24°.

The study area is in Mediterranean climate in macroclimate types. According to the data obtained from Edremit meteorological station, mean annual temperature is 15.7°C. Mean temperature never goes below 0°C. However, the temperature decreases below 0°C from time to time (14 days in the year). The coldest month is January and the temperature is approximately 6.7°C. In summer months characterizing hot period, the mean temperature is 25.7°C in August. The highest mean temperature is 32.4°C in August and the lowest mean temperature is 3.5°C in January. The maximum temperature is 40°C in July and the minimum temperature is -8°C in January, in the year 1973.

The mean annual rainfall vary from about 650 mm on the southern part to over 1200 mm on the Kaz mountains on the north. Annual average rainfall is 659.1 mm and the most of this precipitation occurs in winter months which are parallel to the Mediterranean macroclimate character. In this case, while the total precipitation of 3 months in winter period is 328.2 mm, but the area receives only 22 millimeters rainfall in summer period (June, July and August).

The mean number of days with snow cover may reach 1 per year. Although winds from the east and south-east still dominate, other directions are observed with significant frequency. Winds shift direction in the year, but direction is much more variable during winter.

The dominant wind direction is easterly in winter and southeasterly in summer and the mean wind speed is 2.2 m sec^{-1}. Also in the coastal zone, NE directional etesian winds blow out over the area in the period from May until September. Average speed of southeasterly winds is 4.5 m sec^{-1} .

Annual average relative humidity is 63%. Maximum relative humidity values usually occur during winter period. The absolute humidity in winter months increases up to 70%, but it decreases in summer months to 49%.

The number of cloudy days differs from season to season. The mean number of cloudy days is (57.9 days) lower than mean number of clear days.

According to Thornthwaite (1948), the study area was classified as (c2b2 s2b3), which is semi humid, second- degree mesothermal, under a sea climate effect and has a strong water deficit during summer.

The soils are generally entisols and inceptisols (taxonomy classification) at the higher altitudes. Vertisols occur on the lower parts on the south. The soils are mostly coarser textured and shallower. Four types of soil textures were determined such as, clayey, silty, loamy and sandy soils. These properties of the soil have an importance in determining susceptibility of the soil to erosion. Degraded lands remain with little vegetation cover. But areas dens in vegetation are substantially richer in enclosures than in open areas.

Forest and forage generally cover the northern part of the study area, while dry farming and forage are common in the southern part of the Şahin creek catchment.

Most people in the area engaged in agricultural activities. Almost all the cultivation takes place in the southern part. There is scattered cultivation in the eastern half of the area with slopes greater than 15% where the soils are inceptisols and vertisols. There is severe erosion taking place in the eastern part of the catchment. The remainder of the area is used for grazing with large numbers of cattle, sheep and goats being herded on the area, which is almost completely denuded of grass and with very little cover.

MATERIALS AND METHODS

Determining the intensity, amount and distribution of erosion has a big importance because of necessity in where and what kind of cautions should be taken. For this purpose, many different techniques are being discovered in order to estimate and calculate the carried soil amount (Doe *et al*., 1999; Doğan and Küçükçakar, 1994; Ekinci, 2006). The Universal Soil Loss Equation (USLE; Wischmeier and Smith, 1978) or the revised version of USLE (RUSLE; Renard *et al*., 1997) is often used to predict rainfall erosion in landscapes using GIS.

In this study, Revised Universal Soil Loss Equation RUSLE 3d technique was used, because of its being an enable application to give verisimilitude results in quality and quantity and for detailed evaluation of the factors affecting erosion in computer technology. Modeling soil erosion by RUSLE a functional model derived from the analysis of intensive soil erosion data, has seen wide application in long-term water erosion prediction (Renard *et al*., 1997).

Required GIS data layers included precipitation, soil characteristics, elevation and land use. Current cropping and management practices and selected, feasible, future management practices were evaluated to determine their effects on average annual soil loss. Substantial reduction in water erosion can be achieved when future conservation support practices are applied. In order to determine the potential erosion risk zones and these zones' being classified in the study area, by the improvement of Universal Soil Loss Equation (USLE) (Wischmeier *et al*., 1958; Renard and Freimund, 1994; Wischmeier and Smith, 1965, 1978) Revised Universal Soil Loss Equation (Renard *et al*., 1991, 1994, 1997; Renard and Ferreira, 1993; Sivertun and Prange, 2003; Knijft *et al*., 1999; Lufafa *et al*., 2003; Millward and Mersey, 1999; Mitasova *et al*., 1998). The DEM was imported to the ArcInfo grid format. The improved TIN was then converted back to a 10 m grid.

The RUSLE/GIS methodology permits calculation of potential soil loss from sheet and rill erosion for rangelands (Fig. 2). The RUSLE equation calculates potential erosion (A) as follows:

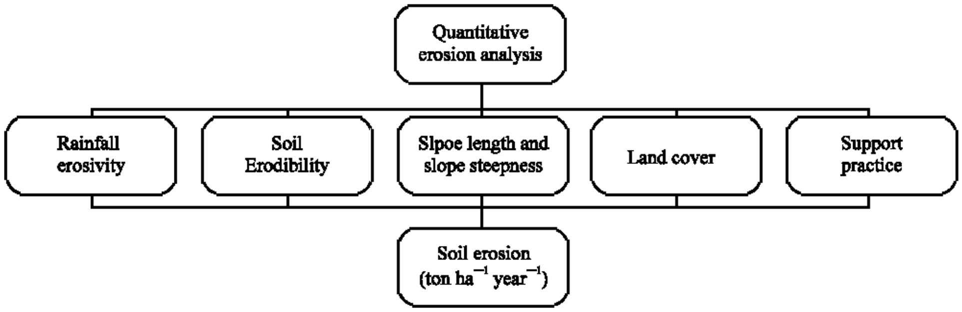

Fig. 2: Evaluation of effected factors with RUSLE 3d

$$A = R . K . SL . C . P$$

A = Average soil loss (ton ha^{-1} $year^{-1}$)
R = Rainfall erosivity factor
K = Soil erodibility factor
SL = Slope length and slope steepness factor
C = Land cover and management factor
P = Support practice factor

The 1/25000 scaled topographical maps of the study area are transformed into computer by scanning and digitized in this area. As a consequence of this process, three dimensional digital elevation model of the basin was formed. Land cover features are obtained in the consequence of classifying of Landsat 2006 ETM+ images. Soil properties are ordered according to the inventory prepared by SoilWater General Management. By taking into consideration of gradient, fauna and soil features that have effects on erosion; a sensitivity classifying was formed in terms of their effects on erosion. Basic maps being used during this application have 10 m resolution transformed in cellular data and their grid interrogations are made. Each equal dimensioned cell has values belong to many factors like slope by taking into consideration of its position; gradient, distance, land cover and soil. The notation of these values is prepared in nominal and ordinal data types. Each of these data put through a cellular based local analysis and results are evaluated separately.

In the consequence of the analysis of findings in the study area, five different potential erosion risk degrees are determined. The areas of these risk degrees and their distributions are mapped. Moreover, annual soil loss is calculated per hectare and data used to develop maps and tables.

Soil loss equation factors in the study area

Rainfall erosivity: R-factor values were calculated from over 25 years of rainfall intensity data from Edremit meteorological station for our study. Derived relationships between the R factor and MFI developed by Arnoldous (1980) recommended using;

$$\text{Former; } MFI = \sum_{i=1}^{12} \frac{pi^2}{P}$$

$$\text{Latter; } R = (4.17\ MFI)-152.$$

Where:
MFI = Fournier Index (mm)
p_i = The average monthly precipitation (mm)
P = Represents the average annual total rainfall rate (mm)

Another topic which is necessary to express is, changing of precipitation in elevation zones. As it is mentioned that the meteorological station Edremit where we obtained the meteorological data is situated on 0 m from sea level. But the elevation changes between 0 to 1765 m in the study area.

Here, Schreiber's method was applied for determining the precipitation change according to the elevation Table 1. According to Schreiber's method;

Table 1: Erosivity factor to elevation levels (m)

Elevation levels (m)	MFI	R
0-120	85.75	205.57
120-220	87.91	214.60
220-320	90.41	225.01
320-420	93.17	236.51
420-520	96.14	248.91
520-620	99.29	262.04
620-720	102.59	275.80
720-820	106.01	290.08
820-920	109.54	304.80
920-1020	113.17	319.90
1020-1120	116.87	335.34
1120-1220	120.64	351.06
1220-1320	124.47	367.03
1320-1420	128.35	383.22
1420-1520	132.28	399.61
1520-1620	136.25	416.18
1620-1720	140.26	432.90
1720-1765	141.47	437.94

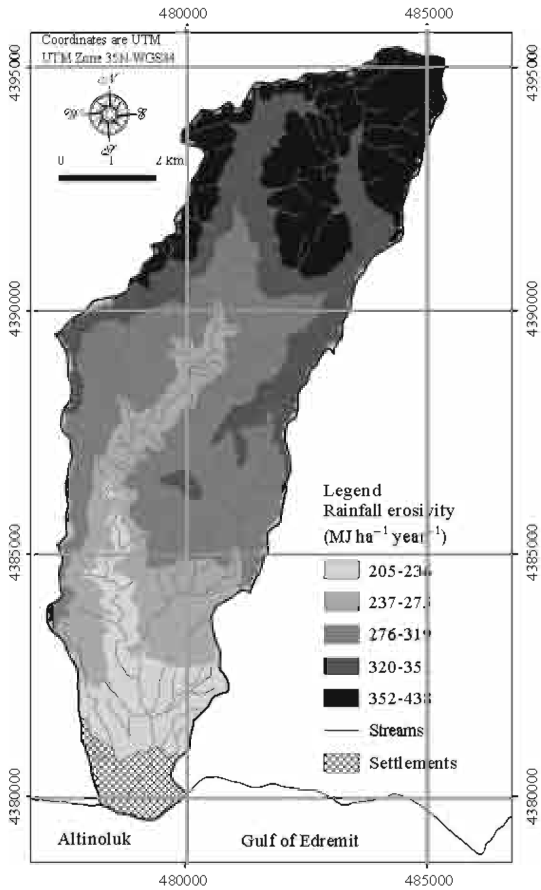

Fig. 3: Rainfall erosivity factor distribution map

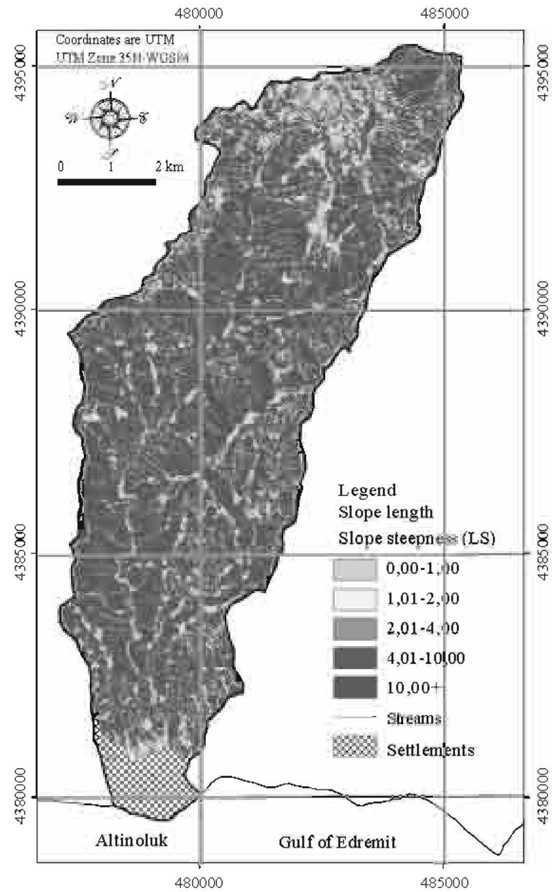

Fig. 4: Slope length and slope steepness factor distribution map

Ph = Po + 4.5 x h (Ardel *et al.*, 1969).

In Schreiber's method, Ph is the average monthly precipitation (mm) and Po represents the amount of average monthly rainfall (mm) at chosen meteorological station and h is elevation of the place which the precipitation will be calculated (Ardel *et al.*, 1969).

According to $MFI = \sum_{i=1}^{12} \frac{pi^2}{P}$;

For 0 -120 m level;

$$MFI = \sum_{i=1}^{12} \frac{109.7^2 + 85.5^2 + ...}{659.1} \Rightarrow MFI = 56.398$$

Latter; the R or Erosivity Factor Rainfall intensity data are difficult to collect and summarize. We use the modified Fournier's index (1960) which has been shown well correlated to Arnoldous linear R (1980) within this region. In addition to this when F was > 55 mm ⇒ (r^2 = 0.75), here (Fournier, 1960; Arnoldous, 1977, 1980; Oduro-Afriye, 1996; Gabriels, 1993; Renard and Freimund, 1994; Bayramin *et al.*, 2006; Diyotato, 2004).

According to R = (4.17 MFI)-152;

For under 120 m level; R = (4.17×85.75)-152 ⇒ R = 205 MJ./ha/year.

Slope length and slope steepness factor: The LS factor represents erodibility due to combinations of slope length and steepness relative to a Standard unit plot. The L and S factors are commonly combined as LS and referred to as the relief factor. LS factor was generated the L and S factors from a Digital Elevation Model (DEM) within a GIS. The two inputs to the LS factor are cumulative slope length and slope steepness (Fig. 3, 4).

To incorporate the impact of flow convergence, the hillslope length factor was replaced by upslope contributing area (Moore and Burch, 1986a, b; Mitasova *et al.*, 1996; Desmet and Govers, 1996).

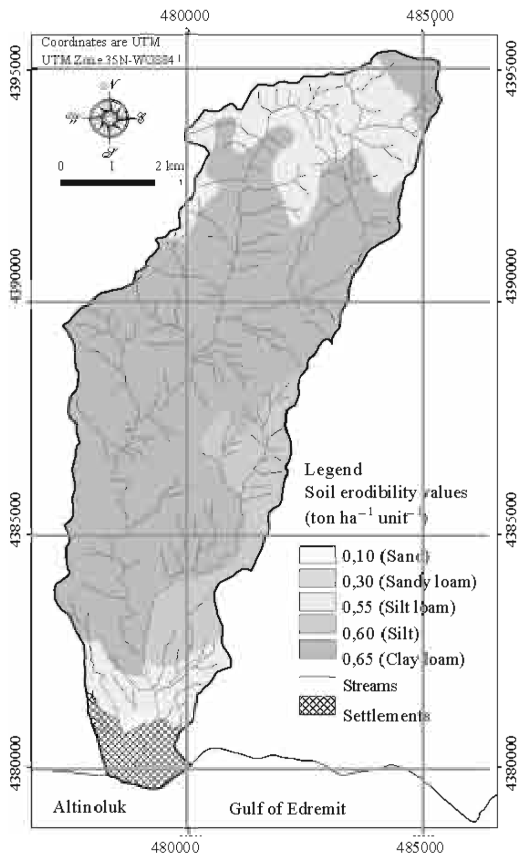

Fig. 5: Soil erodibility factor distribution map

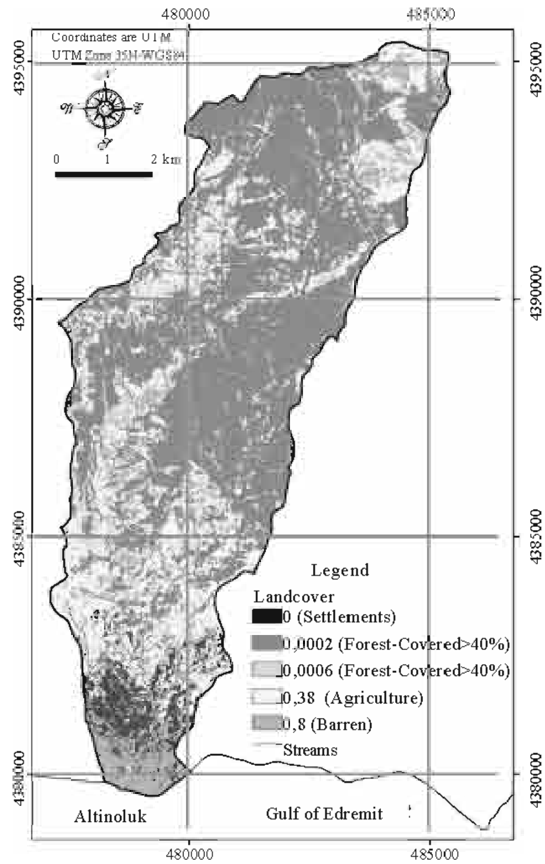

Fig. 6: Landcover factor distribution map of the şahin creek watershed

The modified equation for computation of the LS factor in GIS in finite difference form for erosion in a grid cell representing a hillslope segment was derived by Desmet and Govers (1996). A simpler, continuous form of equation for computation of the LS factor at a point r = (x,y) on a hillslope (Mitasova *et al*., 1996) is:

$$LS\ (r) = (m+1)\ [\ A(r)/a_0\ ]^m \times [\sin b(r)/b_0]^n$$

Where:

A(m) = Upslope contributing area per unit contour width
b(deg) = Slope, m and n are parameters
a_0 = 22.1 m = 72.6 ft., is the length
b_0 = 0.09 = 9% = 5.16 degree is the slope of the standard RUSLE plot (Moore and Wilson, 1992)

It's mentioned that the basic input data for the LS map are a digital elevation model, produced by the General Command of Mapping, Turkey (GCMT). Map of slope gradients has been derived from a digital elevation model. The DEM was imported to the ArcInfo grid format. The improved TIN was then converted back to a 10 m grid. They are treated as water outflow and their removal avoids unrealistically high flow accumulation values. The technique for estimating the RUSLE 3d LS factor that will be applied in this study was proposed by Mitas and Mitasova (1999).

Its mentioned that here LS is calculated using the ArcInfo hydrological extension and by producing flow accumulation grid as proposed by Desmet and Govers (1996) and Sivertun and Prange (2003) from a DEM with a cell size of 10 m.

Soil erodibility (K) factor: The K factor represents both susceptibility of soil to erosion and the amount and rate of runoff. Soil texture, organic matter, structure and permeability determine the erodibility of a particular soil (Fig. 5). The 1:100,000 scale soil map prepared by the Turkish General Directorate of Rural Services (GDRS) Soil and water Resources National Information Centre in 2000 (http.khgm.gov.tr) was used (Fig. 6). Soil structure

Table 2: Soil types and K values

Factor	Soil type	RUSLE 3d values
Soil (K) (tons ha^{-1} $unit^{-1}$)	Sand	0.10
	sandy loam	0.30
	silt loam	0.55
	Silt	0.60
	Clay loam	0.65

Table 3: Land cover factor properties

Factors	Classification	RUSLE 3d values
Land cover (C)	Forest (Covered >40%)	0.0002
(dimensionless)	Forest (Covered <40%)	0.0006
	Agriculture	0.3800
	Barren	0.8000
	Settlements	0.0000

Table 4: Support practice factor values

Factor	Classification	RUSLE 3d values
Support practice (P)	Forest (Covered >40%)	1.00
(dimensionless)	Forest (Covered <40%)	1.00
	Agriculture	0.19
	Barren	1.00
	Settlements	0.00

affects both susceptibility to detachment and infiltration. Permeability of the soil profile affects K because it also affects runoff.

The soils of the study area are divided into five groups, pointing in each group to the texture. K values for various soil types in the study area are shown in Table 2.

Land cover and management (C) factor: The C factor represents the effect of plants, soil cover, below-ground biomass and soil-disturbing activities on soil erosion. The eleven spectrally separable, land cover classes identified; (1) Forest (Covered >40%), (2) Forest (Covered <40%), (3) Agriculture, (4) Barren and (5) Settlements (Table 3).

Support practice (P) factor: The supporting effects of practices like contouring, strip cropping and terraces are described by the P factor. An overall P factor was computed as a product of P factors for individual support practices that are used in combination to reduce erosion (Rijks *et al*., 1998). Information on the support practices or P factor values in the catchment (e.g., contour intervals, terracing) was collected during fieldwork.

Parameter P (support practice factor) was identified in excursion studies. This parameter refers to any practices serving to control erosion, mainly by reducing surface runoff (e.g., terracing, buffer strips and tillage methods). According to RUSLE hand book Renard *et al*. (1997), the only RUSLE support practice applicable to conditions in study area is contour tillage.

P factor values extracted for the purpose of applying the RUSLE 3d in Şahin Creek Basin are shown in Table 4.

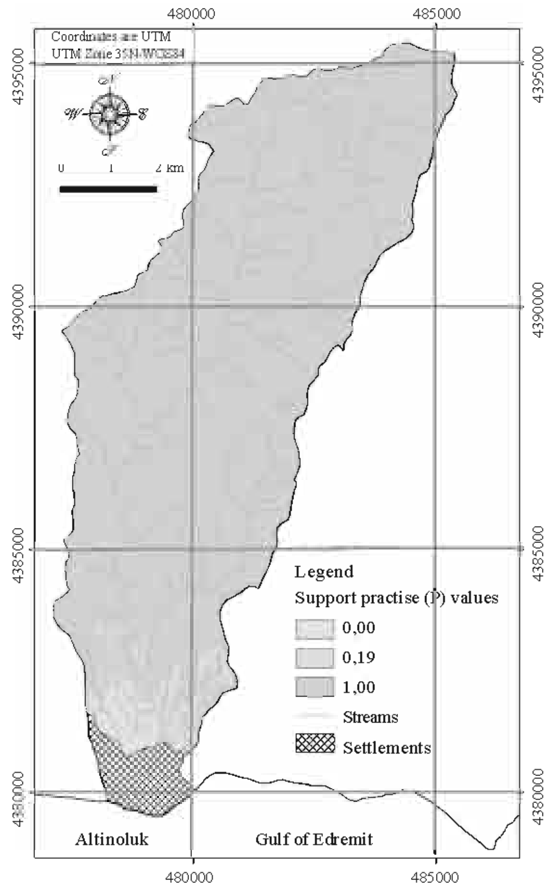

Fig. 7: Support practice factor distribution map

Field examination of the land cover-mapping units revealed that the only form of erosion control being practiced in the catchment is on the Cultivated land-temporary commercial-type-mapping unit. There were examples of contour tillage on these mapping units, as it is shows the Fig. 7 aken of one particular site of commercial farming.

The rest of the Şahin Creek catchment was assigned the P factor value of 1, indicating no physical evident of erosion control in these areas.

RESULTS

In light of data gained as a result of collectively evaluation of different factors by using RUSLE 3d method in Şahin Creek Catchment; deduced in two different results. The first one is determining of potential erosion risk and the other one is estimating annual soil loss. In the first of them, five different erosion risk classes are determined (Fig. 8). According to this data, approximately in 86% of the of study area, erosion risk is not so much

Table 5: Mean annual soil loss quantity (ton ha^{-1} year^{-1}) and rate (%)

Area (km^2)	Soil loss (ton ha^{-1} year^{-1})	Erosion risk	Rate (%)
51.60	0.00-1.00	Low	82.76
6.60	1.01-3.00	Slight	10.59
0.85	3.01-5.00	Moderate	1.36
0.61	5.01-10.00	High	0.98
2.69	>10.00	Severe	4.31
62.35			100.00

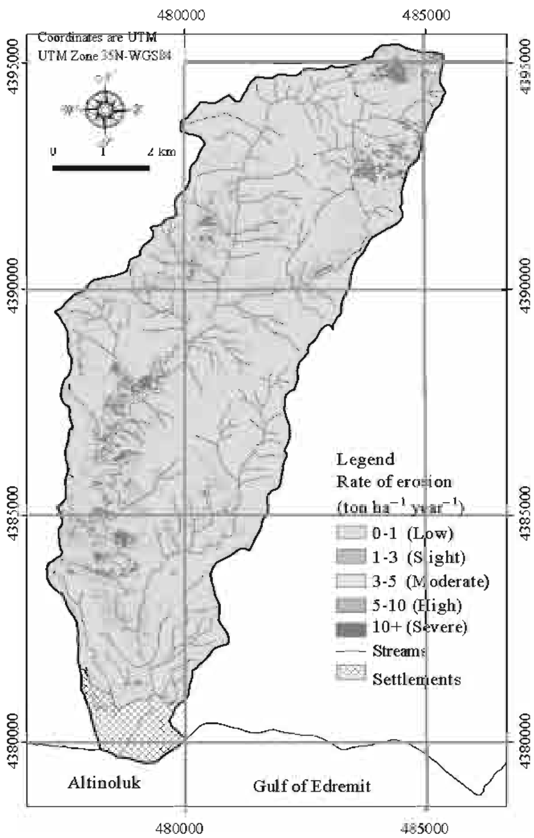

Fig. 8: The classified mean annual soil loss distribution map

(Table 5). But the erosion risk is high on 5.29% of the catchment area. Five erosion risk classes have been determined by taking into account the soil erodibility.

It is estimated that the soil loss of an 82.76% part of the catchment is less than the value of 0.00-1.00 ton ha year^{-1} (Table 5). Approximately 1.01-3.00 tons ha^{-1} year^{-1} soil losses occur on the 10.59% of the catchment. In remain parts of the study area; more than five tons soil loss occur each year. Although the study area has high gradient values, it has low erosion risk basin feature because of the existence of other erosion preventing factors such as dens vegetation cover and low gradient slopes. The density of the vegetation has a role decreasing the effect of high gradient values on erosion intensity. Olive agriculture is the only agricultural activity in the study area. It is common on the lowlands and low gradient slopes of the basin. On this account, the effect of agricultural activities on erosion is indeed low. The areas in which erosion intensity is higher in the basin are open areas that have no land cover and parts which have high valley density and gradient values and the areas in where granular and fine grained soils occur.

CONCLUSIONS

This study describes the application of the RUSLE model, to quantify soil loss in Şahin Creek basin located at northwestern part of Turkey, using the GIS skill. The strategy adopted here is, firstly, to calculate six RUSLE factors using distributed GIS data (e.g., soil, land cover and DEM) to adequately represent the surface characteristics and secondly, to estimate spatial distribution of soil loss in the basin.

The conclusions of the present study are as follows:

- Erosion intensity does not go parallel with inclination.
- Erosion is more effective not only on the steep slopes with poor vegetation cover but also high on barren lands.
- It is identified that in rolled smooth land condition, clayey soil are more erodible than sandy soil.
- Erosion is varying from moderate to sever on the 5% of the study area.

Another important conclusion derived from this research is that the RUSLE can be successfully used for erosion prediction.

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